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DIMINISHING MARGINAL VALUE AS DELAY DISCOUNTING

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The fundamental law underlying economic demand and exchange is the tendency for value of marginal units to diminish with increasing amounts of a commodity. The present paper demonstrates that this law follows from three still-more-basic psychological assumptions: (a) limited consumption rate, (b) delay discounting, and (c) choice of highest valued alternative. Cases of diminishing marginal value apparently due to pure intensity of reward may plausibly be attributed to the above three factors. The further assumption that maximum consumption rate may vary within and across individuals implies that some substances may be unusually addictive and that some individual animals may be unusually susceptible to addiction.

Key words: addiction, choice, delay discounting, diminishing marginal value, economics, substitutability

The main purpose of this article is to show that the economic law of diminishing marginal value, a basic fact underlying choice in psychology as well as economics, arises from a few primitive assumptions:

1. All consumption is constrained. In other words, all commodities are consumed at finite rates.
2. The value of a positive choice alternative diminishes with delay—the time between choice and consumption.
3. Animals always choose the alternative of highest value.

Assumption 1 seems incontrovertible enough to be considered as axiomatic. Patterns of consumption will of course differ across individuals and commodities. Any particular form of the marginal value function will depend on *how* consumption is constrained. But diminishing marginal value (DMV) itself does not depend on any particular consumption pattern.

Assumption 2 also seems incontrovertible. Molar theories of choice (Baum, 1973) do not deny Assumption 2 but seek regularity over temporally extended periods. Molar maximization theory (Rachlin, Battalio, Kagel, & Green, 1981) calculates response rates and reinforcement rates over a more or less wide "window" and assumes that the set of available response rates, together with the reinforcement rate contingent on each, constitutes the set of alternatives to which Assumption 3 is then applied. Molar melioration theory (Herrnstein & Vaughan, 1980) defines a set of alternative situations within which reinforcement rate is calculated and then applies Assumption 3 to individual choices between alternative situations. Either maximization or melioration or both might be consistent with Assumption 2 depending on how a window or a situation is defined and how response and reinforcement rates are calculated. Neither of these molar theories explicitly denies Assumption 2; it is treated as undisputed, if not axiomatic, here.

A much stronger version of Assumption 2 argues that all other apparent forms of discounting may be reduced to delay. For instance, Rachlin, Logue, Gibbon, and Frankel (1986) argued that probability discounting is a form of delay discounting. Bauman (1991) showed that when temporal schedules impose delays of reinforcement equal to those of fixed-ratio schedules, comparable consumption changes are produced. Thus, discounting due to work or effort may also be forms of delay discounting. However only the weaker form of Assumption 2—that reward is discounted by delay—is required for DMV.

Assumption 3 is really a definition. The concept of value in Assumption 3, like the concept of reinforcement, is, without further elaboration, implicitly circular. However, when situations are adequately defined and operations to determine value adequately specified, a strictly behavioral (as opposed to physiological) mechanism is obtained wherein behavior

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in one situation may be predicted from observation of behavior in another. Premack's (1965) theory of reinforcement is perhaps the paradigm of such a mechanism in psychology. In Premack's procedure, relative value is measured as a choice between two alternative responses, and behavior is predicted when one alternative is made contingent on the other. In behavioral economics, utility functions (measures of value) are used to predict behavior under one set of constraints from behavior under another set. A mechanism for breaking the circularity inherent in the concept of value may thus be strictly behavioral—it need not be a physiological mechanism. Unless otherwise indicated, the mechanisms and theories referred to in this article are behavioral. (This is not to say that physiological explanations of DMV are not possible or not useful.)

All existing behavioral theories of choice use "value" merely as a marker to permit discussion of reward parameters separately from behavioral constraints. There is no basis in any existing behavioral theory to predict that an animal will ever freely choose a less valued alternative over a more valued alternative. If an animal apparently does so, the theory must reassess either its method for determining value or its method for determining the effective set of alternatives (i.e., the constraints) or both (Rachlin, 1971). Theories of choice speak of various different parameters of reinforcement (e.g., amount and delay), but an animal's choices may be predicted only through discovery of how various parameters of an alternative combine to determine a single value. Assumption 3 is therefore treated here as axiomatic.

Diminishing marginal value. According to Henderson and Quandt (1958), "It was . . . assumed by the ninteenth-century economists [Jevons, Walras, and Marshall] that the additions to a consumer's total utility resulting from consuming additional units of a commodity decrease as he consumes more of it" (p. 7). This is the law of diminishing marginal value (DMV); it is a fundamental economic law. In fact, because modern economists base their predictions of consumer behavior on DMV, it may be said to be *the* fundamental economic law.

DMV underlies both the economic theory of consumer demand and the economic theory of exchange (Newman, 1965). The theory of demand says that we buy one unit of a commodity (e.g., one apple) because that unit is worth more to us than its price. But as more and more of the commodity is bought, each additional unit is worth less and less until at last the value of the next unit we contemplate adding to our purchase (the marginal unit) is exactly equal to its price. Our choice is always to keep our money (or spend it on something else) or to buy more of the commodity in question. If marginal value steadily declines with amount of a commodity, as DMV says, we will buy exactly enough of the commodity to bring the value of the marginal unit down to the point where it equals its price; marginal units above that point would be worth less than their price and, according to Assumption 3 (common to economics as well as psychology), would not be bought. In other words, we go to the store and buy a dozen apples because the first through 12th apples are each worth more to us than the price of an apple, whereas the 13th apple and all succeeding apples are each worth less than the price of an apple.

Exchange works the same way. If John has all the bread and Mary has all the water, one unit of water is worth more to John (who has none) than to Mary, whereas one unit of bread is worth more to Mary (who has none) than to John. So they both profit from a trade. (For John the "price" of water is so much bread, whereas for Mary the "price" of bread is so much water; for both, the value of the obtained commodity exceeds its price.) But as they trade John gets more water and loses bread, so marginal units of water become less valuable to him while marginal units of bread become more valuable; the opposite is true for Mary. DMV says that John will be willing to trade amounts of bread such that the cost of giving up one more unit of bread equals the gain of getting one more unit of water; the opposite is true for Mary. Exchange would be impossible, according to exchange theory (Newman, 1965), without DMV. But DMV is a consequence of Assumptions 1, 2, and 3. Assumption 1 says that no commodity can be consumed in an instant. Therefore all commodities must be consumed over a finite time period. During that period, consumption rate must either remain constant or decrease or increase. If consumption rate varies bitonically (e.g., decreases and then increases), the period may be divided into finite subperiods in which rate is constant or is monotonically decreasing or increasing. Subsequent sections will show that over periods in which a commodity's consumption rate

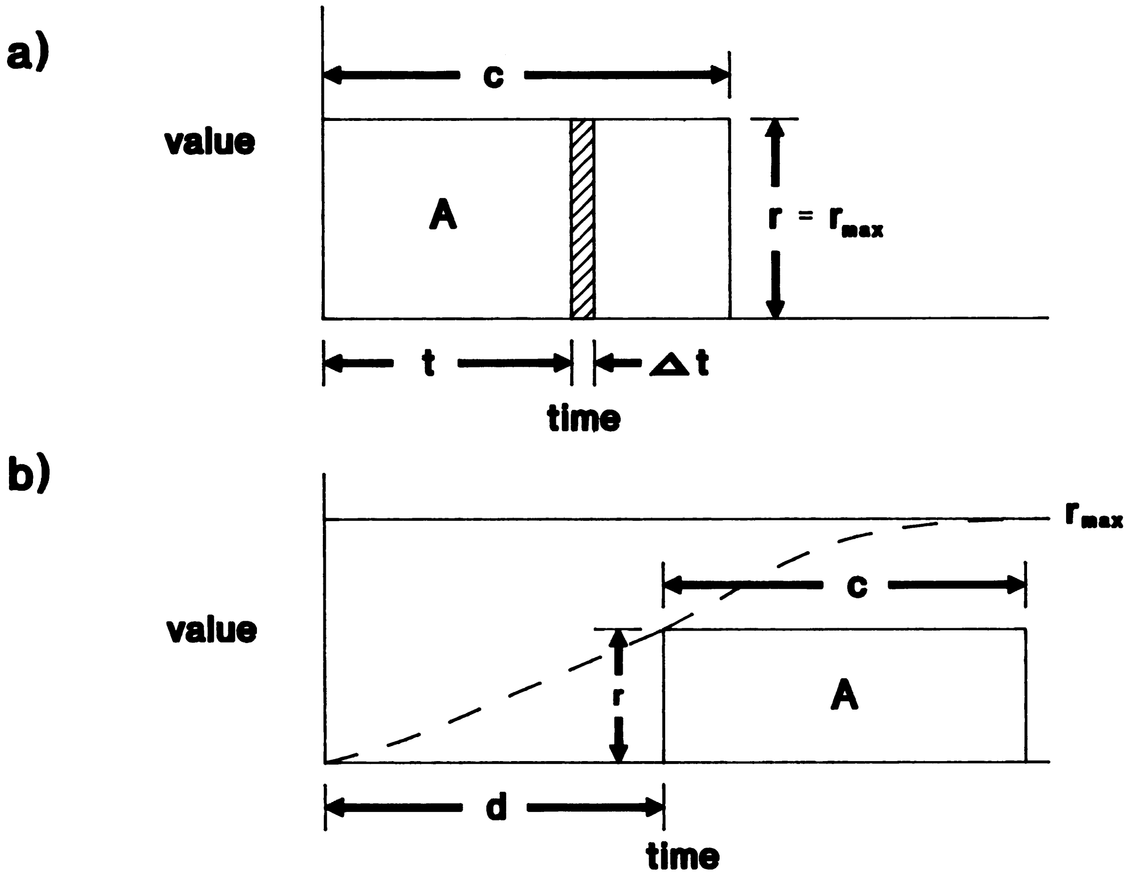

Fig. 1. (a) A rectangular pattern of consumption. An amount (A) of a commodity is consumed at a constant rate (r) until it is exhausted (at time c). (b) A rectangular pattern of consumption of a reward delayed by d units of time. The consumption rate (r) is assumed to be constrained by previous consumption, as indicated by the dashed line as an upper limit. If amount of reward (A) remains constant as delay increases, consumption duration (c) will decrease.

remains constant or decreases, Assumptions 2 and 3 strictly imply DMV. Over periods in which a commodity's consumption rate increases, its marginal value may (but does not necessarily) increase. In such cases DMV is violated.

Constant consumption rate. If you buy 10 apples and it takes 5 min to consume each apple, then the consumption of the 10th apple must be delayed by at least 45 min from the time of purchase; if so, its value must be discounted by at least its 45-min minimum delay. If you buy 20 apples, the value of the 20th apple must be diminished by at least the time taken to consume the first 19 apples (19 × 5 = 95 min). The more apples you buy, the greater the delay to the marginal apple, the greater the delay discount of that apple, the less that apple is worth. Marginal value diminishes with increasing amount of a commodity because consumption of the marginal unit is increasingly delayed (Assumption 2). Consumption of the marginal unit is delayed because it must wait on line, so to speak, for all prior units to be consumed (Assumption 1).

Suppose that any amount obtained of a given commodity (A) is consumed at a constant rate (r) until it is exhausted after a time (c). Figure 1a illustrates the rectangular consumption pattern, a pattern at least not uncommon for animals (Gilbert, 1958). Duration of consumption is amount divided by consumption rate ($c = A/r$). Assuming consumption rate is fixed at its maximum (r_{max}), additional amounts obtained would increase duration of consumption (the rectangle may expand to the right but not upwards).

The best supported available specific form of Assumption 2 is Mazur's (1987) delay discount equation:

$$v = \frac{V}{1 + kd} \tag{1}$$

where V is undiscounted value, v is discounted value, d is delay, and k is a constant reflecting the degree of discounting. Equation 1 has been found by Mazur to describe pigeons' choices among various amounts and delays of food reward as well as humans' choices among various amounts and delays of hypothetical monetary reward (Rachlin, Raineri, & Cross, 1991).

Applying Equation 1 to each subunit of A in Figure 1a gives

$$v = \int_0^c \frac{rdt}{1 + kt} = \frac{r}{k}\ln(1 + kc)$$

$$= \frac{r}{k}\ln(1 + kA/r), \tag{2}$$

where t is time and dt is a derivative with respect to time. Note in Equation 2 that value increases as the logarithm of amount, as Bernoulli claimed in his original postulation of DMV.

Other specific forms of consumption and other temporal discount functions yield different value functions. For instance, if consumption rate (r) decreased over time instead of remaining constant, marginal value would diminish more sharply than Equation 1 predicts; if consumption rate increased over time, marginal value would diminish less sharply and might even increase. Although it is impossible, according to Assumption 1, for consumption rate to increase indefinitely, some commodities may be consumed at increasing rates temporarily. Over those ranges, DMV might not be observed. Such cases will be discussed later.

Decreasing consumption rate. Collier, Hirsch, and Kanarek (1977) showed that rats under free-feeding conditions space their eating in bouts ("meals"). Collier, Johnson, Hill, and Kaufman (1986) plausibly attribute the clustering of eating into bouts to economic factors. By continuing a given bout beyond the point at which the cost of the very next unit to be consumed exceeds its value, the rat may minimize overall costs. The more clustering per day, the fewer number of bouts, the lower the total cost of initiating bouts. What then prevents an animal from clustering all of its eating per day into a single bout? Why not have just one bout per day? On an economic level, this question translates to: Why is the value of an eating bout lower (relative to that of other activities) as the bout progresses? Why does an animal stop eating if starting again will be costly? One conceivable answer is that the inherent value of an activity remains constant as it progresses—it is, rather, the cost measured in terms of other activities given up that increases. But this answer merely avoids the question and poses another: Why does the value of an activity increase as an animal is deprived of it? In fact, both questions are relevant; the value of a consummatory act may decrease while the act is performed and increase while it is prevented. Studies of behavioral contrast (e.g., Green & Rachlin, 1975; Staddon, 1982) indicate a symmetry between the decreasing value of activities as they are performed and increasing value as they are prevented.

It may seem as if one or the other (or both) of the above processes is explained by simple postulation of DMV. But DMV is a *prospective* rule, it pertains to the marginal value of a unit of amount (ΔA) added to a number of units *to be* obtained. In the present analysis, when a 10th unit is added to nine units, all *to be* obtained, the 10th unit must be delayed by the time to consume the first nine. But if the nine units have *already* been consumed, the 10th may be consumed immediately. What then makes it less valuable than the previous nine? One answer, consistent with the present analysis, is that at some central physiological level, consumption rate of the 10th unit is reduced by virtue of the animal's just having consumed the first nine. Digestion, for instance, is most rapid after a period of food deprivation and diminishes as food is taken in (Cannon, 1929). Thus, an animal having just consumed nine units of freely available food must choose between reduction of consumption rate and increase of delay. The animal may consume the 10th unit immediately after the ninth unit, in which case the 10th unit's value will be reduced by the fact that its within-unit consumption rate (r) will be low. Or the animal may delay consumption of the 10th unit until its rate can be higher; then its value will be discounted by the delay itself. An animal just having consumed nine units of food and about to consume a 10th unit is thus faced with a conflict between value reduction due to physiological reduction of consumption rate and value reduction due to delay discounting. Either of these value reductions can be avoided, but only at the cost of the other.

The conflict is illustrated in Figure 1b. The dashed line is a hypothetical refractory constraint on consumption rate of an nth unit of a commodity ($n > 1$). Duration of consumption of the unit (c) is assumed to be short so that consumption rate *within the unit* is relatively constant. Amount (A) is now the amount of the unit. By the same reasoning underlying Equation 2,

$$v = \int_{d}^{d+c} \frac{r\,dt}{1 + kt} = \frac{r}{k} \ln\left(\frac{1 + kd + kA/r}{1 + kd}\right), \quad (3)$$

where d is delay to the nth unit, c is duration of consumption of the nth unit, r is rate of consumption of the nth unit, A is amount of the nth unit ($c = A/r$) and k is a constant measuring degree of delay discounting.

In Equation 3, value varies inversely with delay (d) and directly with consumption rate (r). But (as the dashed line demands) consumption rate itself varies directly with delay. The point of maximum value would be at a delay that balanced these opposing tendencies. The lower the slope of the dashed line, the greater the delay to the point of balance. Meal spacing and meal duration (Collier et al., 1986) may therefore result directly from such consumption constraints.

The behavioral mechanism underlying the reduction of maximum consumption rate with successive units consumed implies the existence of an underlying physiological satiation mechanism. As it affects actual consumption, physiological satiation may act through a rate envelope such as illustrated by the dashed line of Figure 1b. Of course, for different commodities and different organisms, these mechanisms and their rate envelopes will differ.

It may be argued that DMV is explained by such physiological satiation mechanisms without the behavioral delay-discounting mechanism discussed above. There are two answers to this argument: First, without delay discounting, there is no reason why animals should not simply space out consumption of any commodity, no matter how large in amount, to maximize value. If that were done, DMV would not be observed. That is, without delay discounting, satiation would not result in DMV. On the other hand, as demonstrated above (Figure 1a), delay discounting results in DMV even without satiation. Thus delay discounting is a more fundamental explanation of DMV than is physiological satiation.

Nontemporal diminishing marginal value. The fact that DMV is derivable from Assumptions 1, 2, and 3 does not strictly imply that all instances of DMV are due to temporal discounting. It may be that in addition to the temporal DMV implied by Assumptions 1, 2, and 3, there is another DMV of pure reward intensity. Of course it would be impossible to prove that no pure-intensity DMV exists, but it is possible, in a purely speculative way, to examine some apparent instances of nontemporal DMV and point out plausible underlying temporal processes for them.

Two examples of apparent nontemporal DMV are reinforcing electrical brain stimulation (EBS) and sucrose concentration. In the case of EBS, however, degree of reward is typically manipulated in the form of rate or number of pulses of equal intensity. Where it is so manipulated, Assumptions 1, 2, and 3 predict that DMV will be observed, as is the case (Green & Rachlin, 1991). Variation of intensity of EBS seems not to be a convenient way to manipulate its value. Below a certain threshold EBS has no rewarding effect; above a certain threshold EBS may spread beyond the point of application and may stimulate other centers, including pain centers. Between these thresholds there seems to be no evidence for DMV (Hoebel, 1988; Hursh & Natelson, 1981).

Marginal increments of sucrose do indeed diminish in value with concentration in a water solution and in fact eventually become negatively valued. But sucrose, as it affects the physiological taste mechanism, is a complex commodity. The reason for the decline in value of sucrose with intensity of concentration is that as its concentration increases, sucrose begins to stimulate bitter as well as sweet receptors. The same is true of saccharin, but at an even earlier stage (Bartoshuk, 1988). Recruitment of another sensory system with increases in intensity cannot be a model for DMV because the increments in intensity are not truly marginal. A corresponding situation would be the progressive addition of punishment with high reward levels. The diminishment of value due to the addition of the punishment would not be attributable to DMV of the reward but to the aversiveness of the punishment. The test for marginality requires choice of the extra commodity (like an extra apple) when it is not extra. In the present case, the question is, would the recruited system (the punishment) be voluntarily activated? Presumably, it would not. Still another example of sensory recruitment leading to DMV is warmth. The diminishing positive value of heat with intensity is due to the progressive activation of cold and pain systems in addition to warmth (Jenkins, 1951). Again, the apparent DMV is due to the addition of punishment and not an intrinsic decrease in reward value.

Consider a possible way to get around DMV. Suppose you've bought 10 apples (because the value of each was greater than its price) and not more (because the value of the 11th and all succeeding apples was less than their price). You might still buy an orange or a pear. Originally you bought apples because, relative to their price, you like them better than oranges or pears. But because of DMV, the first orange or the first pear might be worth more than the 11th apple. The economic concept of *degree of substitutability* is an attempt to quantify the relationship among different commodities, like John's bread and Mary's water in a previous example. (See Green & Rachlin, 1991, and Rachlin et al., 1981, for behavioral analysis using the concept of substitutability.) To the extent that an orange or a pear is substitutable for an apple, it must wait on line just like another apple to be consumed after the first 10 apples. However, to the extent that oranges and pears are not substitutable for (or are complementary to) apples, they may be consumed along with apples. Whether a consumer would add an orange or two or a pear or two to a basket of apples depends both on the degree of substitutability of oranges and pears for apples and on the prices of all three fruits.

In the complex conditions of everyday life, many apparent increments in reward intensity are actually collections of more and more commodities in a package. Although 10 apples are worth less than 10 times one apple, 10 bowling pins are worth more than 10 times one bowling pin, and a right shoe plus a left shoe is worth much more than twice the value of a right shoe alone. The latter two cases are not violations of DMV but are the addition of nonsubstitutable (in these cases, complementary) goods.

The addition of first-class amenities to an airplane flight or the addition of significance in the standings of an important baseball game to the fun of watching a game is like the addition of an orange to a bag of apples—they may be considered increments of intensity only to the extent that they are substitutable for the basic good being bought. When a person's diet is suddenly increased in variability (presumably adding not-completely-substitutable goods), food intake increases correspondingly (Rolls et al., 1981). Rats given a highly varied diet ("supermarket foods") increase consumption to the point of obesity (Scalfani & Springer, 1976).

In the case of an airplane flight the fundamental good you are buying is time at your destination or your point of origin, or both. The faster the flight, the more time you have. To pay extra for a faster flight (say on the Concorde) means that the time saved is worth more to you than to other people. Time saved is subject to DMV exactly as Assumptions 1, 2, and 3 imply. However, when you upgrade to first class from tourist class, you are buying something other than transportation; it is like buying oranges along with apples. Whether you do or do not purchase a more comfortable seat, a more elaborate meal, free drinks, more attention, and more prestige depends on the value of these items, how much they cost, and the degree to which they perhaps complement the trip.

One other conceivable objection to a temporal analysis of value might arise. It might be claimed that the probability of an outcome affects its value and that probability is not temporal. One answer to this objection is that there is no evidence of DMV with probability. Marginal increments of probability are not less valued at high than at low probabilities; in fact, the reverse is typically the case (Rachlin, et al., 1991). Another measure of riskiness, odds-against, does show DMV, but as Rachlin et al. (1986) argue, odds-against is actually a temporal measure; odds-against is equivalent to the average waiting time for a positive outcome of a repeated gamble. Thus, there is no evidence against the temporal basis of DMV in probabilistic choice experiments.

The point of the above discussion is that at least it is not a trivial exercise to find examples of DMV that cannot plausibly be attributed to Assumptions 1, 2, and 3.

Increasing consumption rate. Imagine a consumer with a fixed budget in a universe with only two commodities—say, apples and oranges. With a fixed budget, fixed prices, and fixed degree of substitutability (fixed utility function), microeconomic theory accounts in a straightforward way for the mixture of apples and oranges that the consumer will buy (Rachlin et al., 1981). But now suppose that for each apple bought the grocer reduces the price of the next apple by 1 cent but leaves the price of oranges constant or even increases it. As time goes on, in this situation the consumer will purchase more and more apples and—because of the limited budget—fewer and fewer oranges. Suppose at last a limit is reached below which the price of apples will not decrease. How many apples and oranges will be in the basket at that point (or whether there will be any of either fruit at all) depends on the degree of substitutability between apples and oranges. If the two fruits are highly substitutable for each other, there will be no oranges or very few oranges in the final basket. In the extreme case, where the two commodities are completely substitutable (e.g., white eggs vs. brown eggs rather than apples vs. oranges), there would be none of the high-priced commodity left at all. This last case would be equivalent to a constant fixed-ratio (FR) schedule, programmed concurrently with a progressively reducing FR schedule with identical (therefore completely substitutable) reinforcers. Concurrent ratio schedules eventually yield exclusive responding to whichever ratio is shorter (Herrnstein & Loveland, 1975).

At the other extreme, if the two commodities were completely complementary (e.g., left shoes vs. right shoes considered as separate commodities), the ratio of the commodities consumed would remain constant regardless of their relative prices. This case would be (almost) equivalent to concurrent ratio schedules of food versus water (Rachlin et al., 1981). Although food and water are not complete complements (like left and right shoes) altering their relative prices has little effect on the ratio of food to water consumed by a rat.

Now consider not apples versus *oranges* but apples versus *all other commodities.* Now instead of "substitutability" between one commodity and another wherein the price of each commodity is the amount of the other given up, we talk of "elasticity of demand." If X is highly substitutable for many other commodities, demand for commodity X is said to be highly elastic. If there are few substitutes for that commodity among other commodities, demand for it is said to be inelastic. When demand for a commodity is elastic, the amount of it bought is sensitive to its price in terms of other goods given up for it (money-cost being a measure of price). Thus, if (contrary to normal practice) a grocer were to decrease the price of apples for each apple bought without limit *and* if (contrary to fact) the demand for apples were extremely elastic, a runaway positive feedback system would result—the more apples bought the lower their price (due to the grocer's pricing method) and the lower the price of apples the more would be bought (due to the elasticity of demand for apples). Eventually apples would be the only commodity bought. At that point the consumer might well be viewed as "addicted" to apples.

Grocers seldom reduce real prices as a function of the number of units previously bought (although they do reduce prices for bulk purchases), but the present analysis suggests that there are some commodities the *effective* price of which is reduced as consumption progresses. The connection between effective price and the present analysis rests on the fact, illustrated by Equation 2, that the value of a *fixed amount* (A) of a commodity increases with consumption rate (r). The greater the consumption rate of a commodity, the greater its value. If the value of a fixed amount of a commodity increases, its effective price (cost per unit of value) decreases, even though its nominal price (cost per unit of amount) remains constant.

Thus, the present analysis provides a mechanism by which an animal might reduce the effective price of a commodity—by increasing consumption rate. As indicated previously, consumption rate may normally be expected to remain constant or decrease as consumption progresses. (Skinner's earliest published studies [e.g., 1932] fitted the course of consumption with a power function with a less-than-unity exponent.) Furthermore, Assumption 1 implies that even if consumption rate increased, it could not increase indefinitely; no commodity could be consumed at an infinite rate. Nevertheless, there certainly are cases in which consumption rate may increase temporarily, even over long periods.

Consider commodities like cigarettes and alcohol that are notoriously difficult for neophytes to consume (all that coughing and vomiting). The more cigarettes smoked and drinks drunk, the more opportunity to learn to smoke and drink efficiently; the more efficiently cigarettes are smoked and drinks are drunk, the more rapidly they may be consumed (higher $r_{\max}$); the more rapidly they are consumed, the more valuable they are; the more valuable they are, the more will be bought; the more bought, the more smoked and drunk, and so on until the limits of smoking and drinking efficiency are reached. (Speculation as to why the very first or the second cigarette is smoked or alcoholic drink is drunk is beyond the scope of the present paper. Social factors, imitation, and similarity to other reinforcers may all play a part.)

It follows that those substances that animals can learn to consume with high efficiency will be consumed at high rates and hence will be enhanced in value relative to substances with strictly limited consumption rates. Similarly, it follows that individual animals that are unusually able to learn to increase consumption rates of various commodities will value them more highly than will individuals whose consumption rates are less malleable. When in addition the demand for those commodities is highly elastic, they will be obtained and consumed in unusually high amounts. When those commodities are harmful if consumed in unusually high amounts by humans (as are cigarettes and alcohol), they will be viewed as addictive substances; people unusually able to consume them rapidly will be viewed as having addictive tendencies.

This economic-behavioral mechanism of addiction is a more specific version of the "positive addiction" mechanism outlined by Stigler and Becker (1977). A positive addiction results from the combination of an elastic demand and a learning process by which increased consumption results in increased value. Stigler and Becker cite examples such as "addiction" to classical music (the more you listen, the more you get out of it), addiction to novels of a given genre (the more you read them, the easier they become to "get into") and other nonharmful increases in consumption. As you "get more out of" a given commodity at a fixed price, its effective price (price per unit of value) decreases. As described above, effective price reduction combined with elastic demand results in increased consumption. The present analysis specifies a mechanism by which value may increase with use—through increased consumption efficiency—and implies that harmful consumption increases as well as nonharmful consumption increases may be positive addictions.

This is not to say that the above behavioral-economic mechanism is the only conceivable explanation of all addictions. There may be more than one kind of behavioral-economic addiction (see Hursh, 1991), and of course various physiological mechanisms underlie the behavioral process. Nevertheless, where abnormal increases in amount of consumption appear to be accompanied by increased efficiency of consumption, the present mechanism may be at work.

In summary, during periods of time when consumption rate remains constant or decreases, the three assumptions described at the beginning of this paper strictly imply DMV. Of the three, only Assumption 2, delay discounting, is empirical rather than axiomatic. Thus DMV may be conceived as a straightforward consequence of delay discounting, provided consumption rate does not increase. During periods of time when a commodity's consumption rate increases, DMV may be violated. If, in addition, demand for the commodity is elastic, unusually high amounts of it may be consumed. Where high amounts of consumption are harmful to an animal, such commodities may be viewed as addictive.

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